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Review

Recycled cathode ray tube and liquid crystal display glass as fine aggregate replacement in cementitious materials

Alaa M. Rashad *

Building Materials Research and Quality Control Institute, Housing & Building National Research Center, HBRC, Cairo, Egypt

HIGHLIGHTS

- Workability increased with CRT and LCD glass sand, whilst density decreased.
- Mechanical strength and water absorption decreased with CRT and LCD glass sand.
- ASR expansion increased with CRT glass sand, whilst drying shrinkage decreased.
- CRT reduced the carbonation resistance, whilst LCD increased sulfate resistance.
- Concrete electrical resistance increased with increasing LCD glass sand.

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ABSTRACT

With the rapid advances in the electronic industry, the disposal of cathode ray tube (CRT) glass and liquid crystal display (LCD) glass has become a major environmental problem. One option for safe environmental and economic disposal of these wastes is to reuse them in building materials. Many past studies have reported that the use of CRT glass and LCD glass waste as a part of fine aggregate and few others reported the possible use as a part of binder material. This paper presents an overview for the previous literature which was carried out on the use of CRT and LCD recycled glass as a partial or a complete replacement of the natural fine aggregate in traditional mortars and concretes based on Portland cement (PC). Fresh properties, hardened properties and durability of these mortars and concretes have been reviewed in this paper. This review showed that using CRT and LCD glass sand in the matrix led to some advantages and some disadvantages. The main disadvantages of using these systems are decreasing compressive strength and increasing the expansion of alkali-silica reaction (ASR).

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* Tel./fax: +20 2 33351564, +20 2 33367179.
E-mail addresses: alaarashad@yahoo.com, a.rashad@hbrc.edu.eg

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1. Introduction

The cathode ray tube (CRT) was first developed in 1897 by Ferdinand Braun as an oscilloscope to view and measure electrical signals [1]. Until the 1920s, the CRT was used as a medium to send and receive images electronically in television systems. Later, the concept of applying colour CRT was introduced in 1949. The basic raw material in the CRT glass is silica (~50–60 wt.%). Other different metallic oxides such as barium oxide and lead oxide are incorporated in CRT glass as shielding agents for harmful radiation [2].

Waste CRT glass which results from discarded computer monitors and TV sets, is classified in European Waste Catalogue 2002 and corresponding national legislation as hazardous waste, meaning it cannot be disposed of to landfill without treatment. This waste contains a large amount of lead (mainly as lead oxide) as well as other heavy metals such as barium and strontium [3,4] The production of CRT in the entire world are 83,300,300 units in 2002 and they can approximately release 83,000 metric tonnes of lead [5]. However, the amount of discarded CRT has lately grown rapidly in the recent years. It is estimated that the amount of CRT TVs disposed in the United States alone is approximately 20 million units each year [6]. It is reported that, in the Western Europe, 300,000 tonnes of CRT is expected to become annually obsolete [7]. Based on the WEEE collection and ore-treatment market, about 50,000–150,000 tonnes of CRT reach the end of their life annually and what are currently collected within Europe and this flux are not expected to decrease in the next years [8]. In the European Union, four-fifths of the total electronic wastes discarded are the CRT waste in 2001, in the United States one-third of total electronic-waste are comprised of CRT in 1999. Some researchers have predicted that by 2050 year, the mass of the CRT waste required to be disposed may be 6 times in the current mass [9].

It is estimated that approximately 2.9 million televisions (74,000 tonnes) and 3.2 million computer monitors (48,000 tonnes) are stockpiled in California in 2005 [10]. In 2006, approximately 163,420 computers and televisions in North America become obsolete every day and the cost of proper disposal or recycling is expected to reach $10.8 billion by the year 2015 [11]. It is reported in literature that in 2002 only in UK alone, 104,532 tonnes of CRT glass is generated out of which televisions contributed 69,000 tonnes and computer monitors contributed 26,000 tonnes [12]. In Thailand, discarded CRTs are increasing problem. It is estimated that 1.9 million televisions, 750,000 computers and 550,000 monitors were sold in 2004, whilst in 2010 approximately 1.5 million televisions and 1.05 million computers were discarded [13]. In Hong Kong, there are approximately 6 million computers being used and approximately 20% of these are replaced annually. It is estimated that more than 490,000 TV sets and CRT monitors are discarded from households every year due to the widespread use of flat screen plasma/LCD/LED TV and monitors in Hong Kong [4].

Through a global perspective, it is estimated that only 26.75% of the discarded CRT are recycled, 59% are landfilled and 14.75% are incinerated [14]. If the CRT waste is not handled properly, the lead (or other heavy metals) included in the CRT glass will pose serious soil and ground water pollution [15]. The number of discarded CRT units has drastically increased as a result of the rapid advances in computer monitor and TV technology, which enables consumers to replace old products frequently.

Currently, developments have quickly shifted displaying monitors from the conventional CRT to liquid crystal display (LCD). The major materials of LCD include 85–87% glass, 12.7–14% polymer and 0.12–0.14% liquid crystal [16]. Liquid crystal is composed of glass substrates liquid crystal, indium-tin-oxide (ITO) conductive glass and black matrix (chromium oxide). It is characterized as an interim state between solid and liquid [17]. The main chemical component of waste liquid crystal glass is SiO_2 [17]. LCD panel is being widely used in LCD monitor, laptop, tablet (slate), mobile phone, television and public display applications due to its high definition and convenience of carrying compared with the other flat panel displays technologies. The service life of LCD used in the notebook is only 3–5 years, whilst used in TV is 8–10 years [18]. Therefore, a huge number of LCD panels would be scrapped with the updating of these devices.

The evolution of the electronic recycling system is of particular interest in western Washington State. The six country region of Whatcom, Skagit, Snohomish, King, Pierce and Thurston Country dispose roughly 27,800 tonnes of computer monitors, televisions and cell phones in 2010, up from approximately 25,000 tonnes in 2003 [19]. In Taiwan the waste of LCD glass is approximately 1000 tonnes every year [20]. In 2005, the Taiwan thin film transistor liquid crystal displays (TFT-LCD) manufacturing industry produced a total of more than 130,000 tonnes of waste, of which 70% is recycled subsequently [21]. Accordingly, the amount of waste LCD glass has increased drastically, which should be resolved in environmental friendly ways by recycling the waste LCD glass as a resourceful material for alternate use. Yet, due to the lack of specific recycling technologies that put economics into consideration, the waste LCD glass has been treated by incineration or buried in landfills. These ways of disposal do not observe the WEEE regulations of the EU [22]. Another option is to reuse LCD glass into other material. LCD glass can be used in manufacturing glass ceramic [23], water-absorbed tile [24] and substitute for cement in cement mortar [17,25,26].

Waste reduction and recycling are very important elements in the waste management framework because they help to conserve natural resources and reduce demand for valuable landfill space. The use of recycled LCD glass in the manufacturing of new LCD glass reduces energy consumption, raw materials use, and wear and tear on machinery. However, not all used LCD glass can be recycled into new glass because of impurities, cost, or mixed colours. There is a need to establish new options for eliminating waste LCD glass. The important option is to recycle waste LCD glass in certain building materials as fine aggregate.

Indeed, there is no referential article summarizes the past studies carried out on the fresh properties, hardened properties and durability of mortar or concrete prepared utilizing CRT glass and LCD glass as partial or complete replacement of fine aggregate. In this article, we do our best to review the past studies which have

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